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COLORADO RIVER SIMULATION SYSTEM

AN EXECUTIVE SUMMARY

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U.S. DEPARTMENT OF THE INTERIOR



Bureau of Reclamation

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AN EXECUTIVE SUMMARY

OCTOBER 1981

In May of 1981, the Secretary of the Interior approved changing the Water and Power Resources Service back to its former name, the Bureau of Reclamation.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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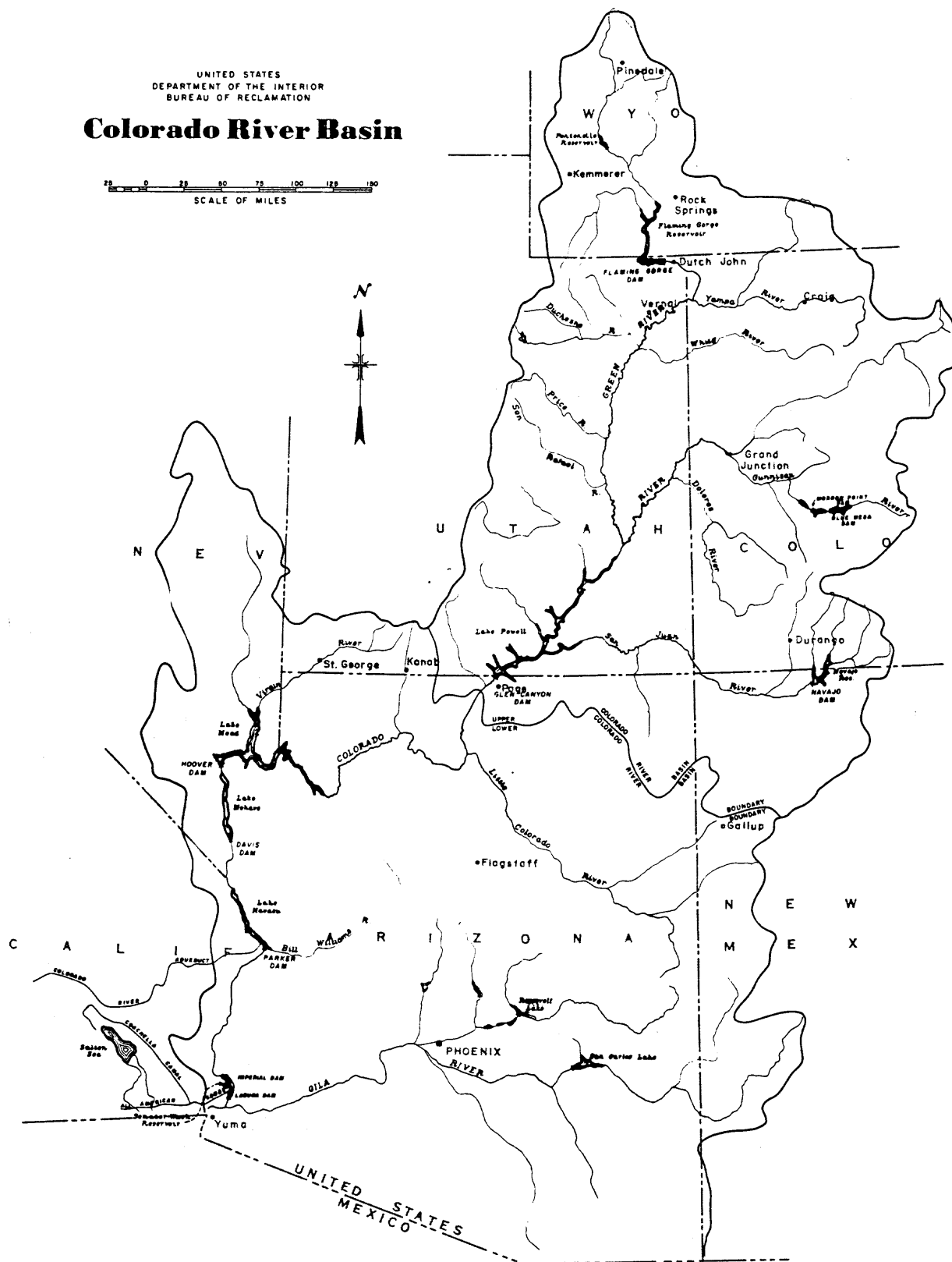
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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Colorado River Basin

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SCALE OF MILES



Colorado River Basin

Introduction

The Colorado River is undoubtedly the most legislated and probably the most regulated major river in the world. There have been more than 20 major legal actions, Congressional acts, United States Supreme Court decisions, intrabasin compacts, and international treaties, that together formulate the "Laws of the River." An important tool for answering the many "what if" questions that are addressed to water resource managers in any complicated river system, such as the Colorado River System, is a simulation model of the system. A simulation model is no more than a computational procedure, but so many calculations are required that without a computer, the task would be impractical. The CRSM (Colorado River Simulation Model), the central feature of the CRSS (Colorado River Simulation System), is a deterministic simulation model that has been developed by the Bureau of Reclamation in accordance with all the "Laws of the River" (see table 1), including the requirements of the "Operating Criteria" for maintaining equal

storage in Lake Powell and Lake Mead as long as sufficient Upper Basin storage exists and for an assumed objective release of at least 8.23 million acre-feet annually from Glen Canyon. With CRSS, proposed changes to the operation or alternative development schemes of the river system can be modeled, and their effect on the future quantity and quality of water in the river may be evaluated. The following programs and data bases constitute the CRSS:

1. CRSM (Colorado River Simulation Model)
2. Operational control data
3. Demand data base
4. Demand input data generation program (SMDID)
5. Natural flow and salt data base
6. Hydrology input data generation program (MHYDRO)
7. Output summary program (TAPEDIT)

The block diagram in figure 1 illustrates the general CRSS flowchart.

Table 1.—Legal and Institutional Documents Covering Operations of The Colorado River System

“LAWS OF THE RIVER”

Supreme Court Decree in *Winters v. United States* - 1908.

Supreme Court Decree in *Wyoming v. Colorado* - June 5, 1922.

Colorado River Compact - November 24, 1922.

Boulder Canyon Project Act - December 21, 1928.

California Limitation Act - March 4, 1929.

Seven-Party Water Agreement - August 18, 1931.

Boulder Canyon Project Water Contracts -February 21, 1930, through the present.

Boulder Canyon Project Power Contracts -April 26, 1930, through the present.

Boulder Canyon Project Adjustment Act - July 19, 1940.

Mexican Water Treaty - November 8, 1945.

Upper Colorado River Basin Compact - October 11, 1948.

Lake Mead Flood Control Regulations -February 18, 1954.

Colorado River Storage Project Act - April 11, 1956.

General Principles to Govern and Operating Criteria for Glen Canyon Reservoirs and Lake Mead During the Lake Powell Filling Period -April 2, 1962.

Colorado River Storage Project, General Power Marketing Criteria - 1962.

Supreme Court Decree in *Arizona v. California* - March 9, 1964.

Judgment of Supreme Court of non-Indian present perfected rights - January 9, 1979. (Indians intervened prior to action and their rights are being litigated.)

Colorado River Basin Project Act (Public Law 90-537, 90th Congress, approved September 30, 1968).

Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs - June 10, 1970.

State Water Laws.

United States v. District Court, Eagle County, Colorado - 1971.

Contracts for sale of water from Colorado River Storage Project Reservoirs.

Colorado River Basin Salinity Control Act (Public Law 93-320) enacted June 24, 1974.

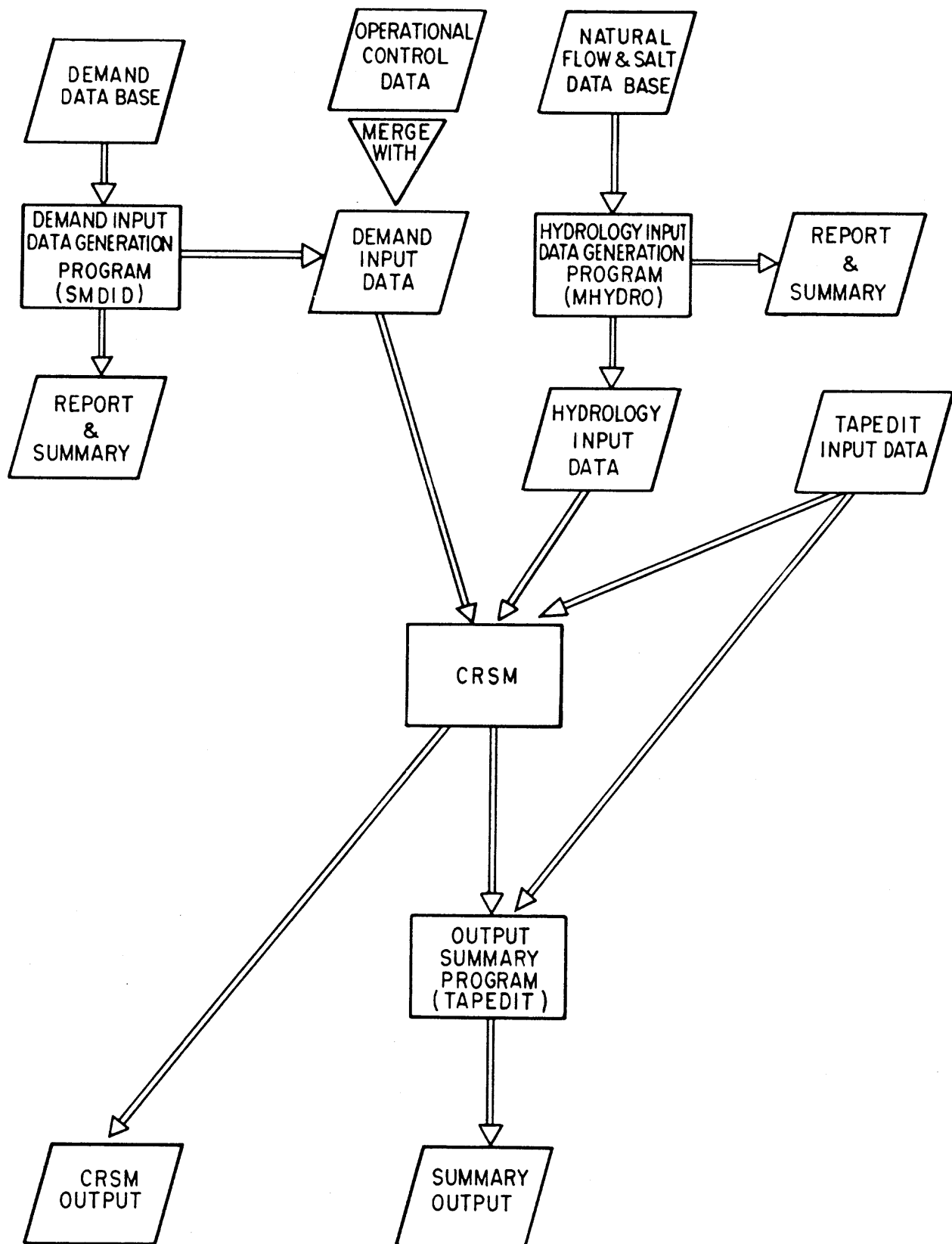


Figure 1.—CRSS Block Diagram

Colorado River Simulation System—General

The CRSS breaks the basin down into various reaches or subbasins. These reaches are then further broken down into sequence points at which inflows, demands on water (diversions), and reservoirs are located. The configuration of the Colorado River Basin as presently modeled consists of 24 reaches. Each reach represents a specific geographic area. Up to 10 inflows and 10 different demands can be identified within each reach. Each demand or inflow is assigned

to a particular sequence point or location within a reach. Currently, there may be only one reservoir per reach. Reservoirs consume one of the 10 inflow sequence points; thus, in reaches where a reservoir is located, 9 sequence points would be available for inflows. The block diagram in figure 2 illustrates the basin configuration as presently modeled. Each block represents a reach. Reach identification is a numerical designation as well as an alphanumeric title. A typical reach schematic is illustrated by figure 3. The basin configuration and reach description data are input to the CRSM, thus providing flexibility.

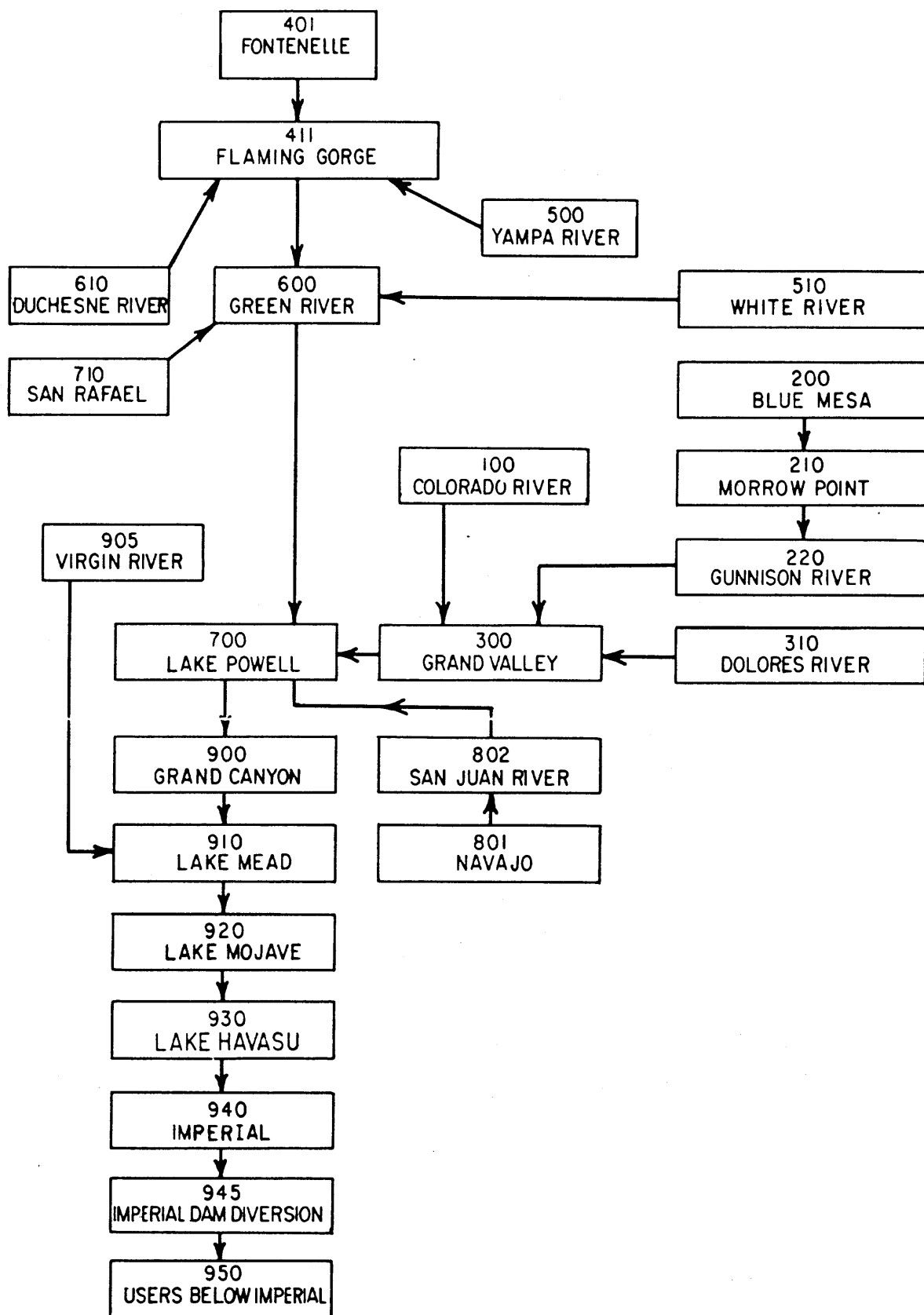


Figure 2.—CRSS Basin Configuration

REACH 401 - FONTENELLE

INFLOW
GREEN RIVER AT FONTENELLE DAM

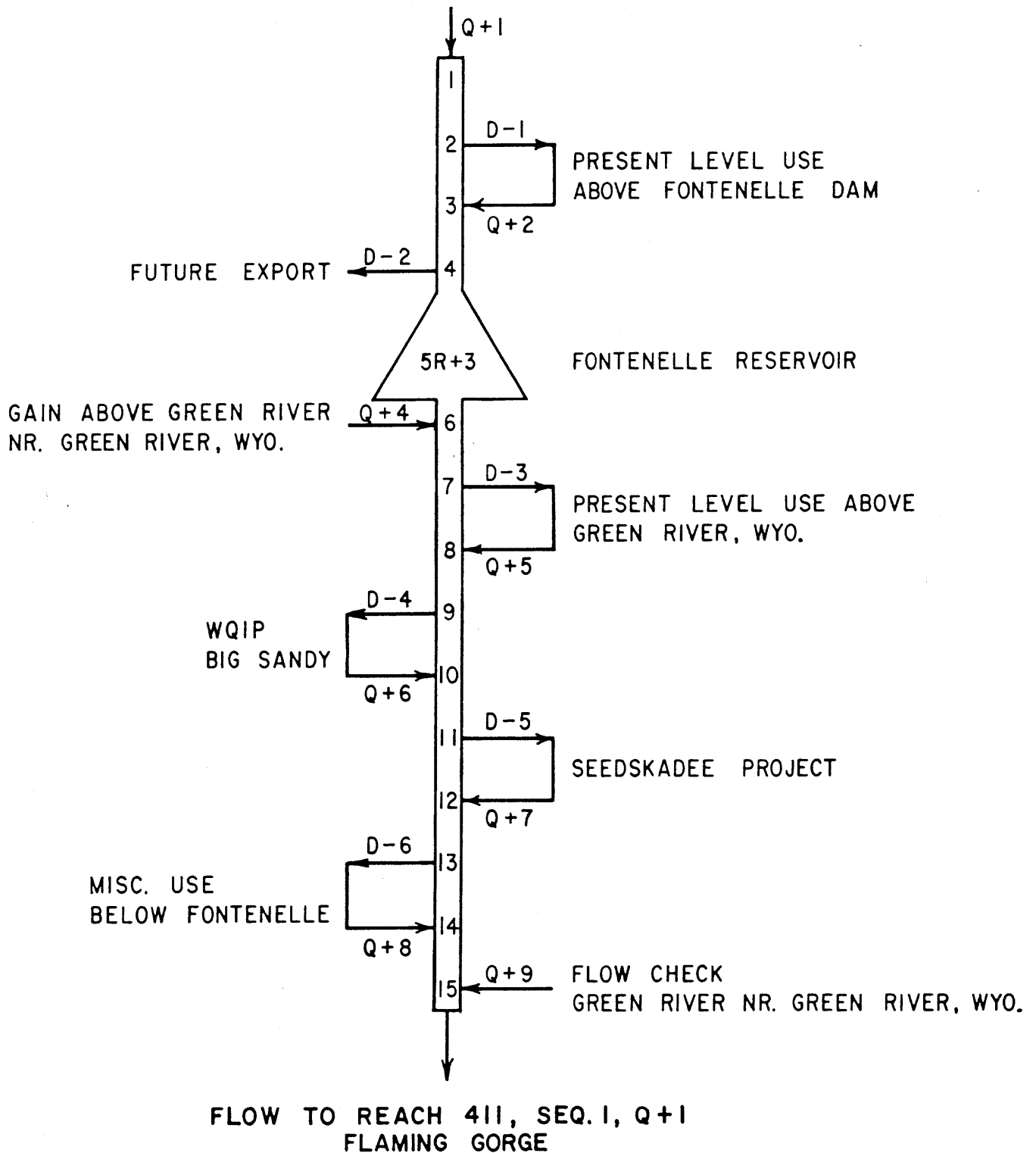


Figure 3.—Reach Schematic

Colorado River Simulation Model

The model simulates river basin flows on a monthly time frame starting at the top of the basin and proceeding completely through the basin to the bottom. Simulation is done reach by reach in an order specified by the basin configuration as input to the model. Within a reach, computations are made from upstream to downstream end.

The general operation of the simulation model is shown schematically on figure 4.

Riverflows are calculated at each inflow, demand, and reservoir sequence point. All calculations for riverflow are based on the continuity equation:

$$\text{Flow at next sequence point} = \text{Flow from preceding sequence point} + \text{Inflow} - \text{Demand}$$

When there is not enough flow in the river at a sequence point to supply a demand, a search is made of upstream reservoirs for the additional water needed. If there are reservoirs upstream with sufficient water in storage, the additional increment needed is released and passed through the system to the point needed. If adequate water is found, the demand is met and the calculations proceed to the next downstream sequence point. However, if the demand cannot be satisfied, the amount of shortage is computed, the available water is diverted, and a shortage message is printed and calculations proceed.

A reservoir is generally operated to meet a target end-of-month contents. A release is determined

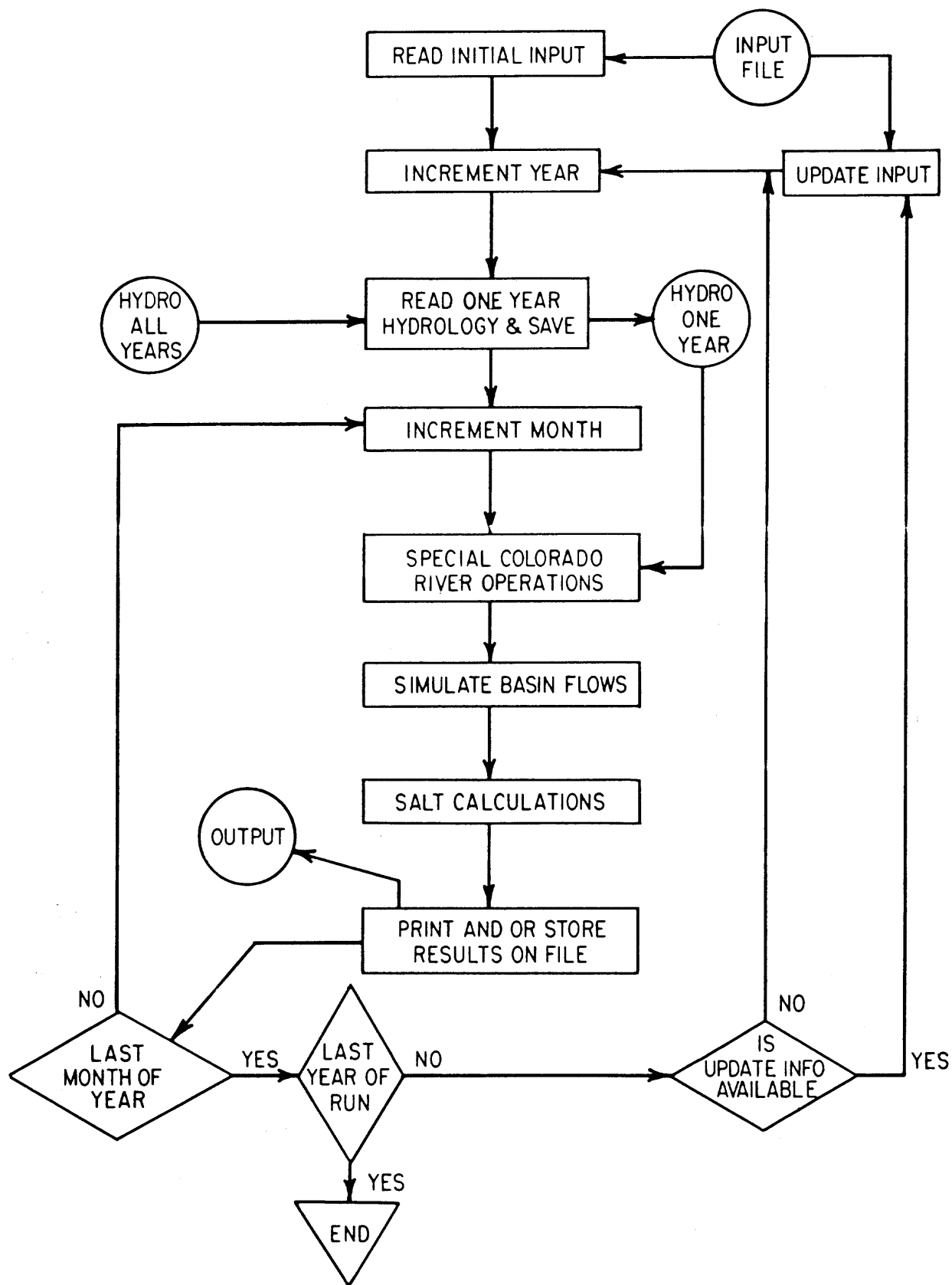


Figure 4.—CRSM Operational Schematic

by either a minimum release rate, a flood space storage requirement, demands which draw from the reservoir, demands which draw from upstream reservoirs and move water through the reservoir, or the "Laws of the River." The operations of Lakes Powell and Mead are largely determined by the criteria and constraints relating to the "Laws of the River." All calculations for reservoir operations are based on another form of the continuity equation:

$$\text{Change in storage} = \text{Inflow} - \text{Outflow} - \text{Evaporation} - \text{Change in bank storage}$$

Evaporation, bank storage, and power production are calculated each time water is moved through a reservoir. Evaporation is determined by a monthly coefficient and the surface area of the lake that month. Change in bank storage is calculated as a percentage of the change in surface storage each month. This percentage ranges from 6.5 percent in Lake Mead to 15 percent in Lake Powell.

After the entire system is in hydrologic balance, salinities are computed throughout the system by a mass balance accounting procedure. Initial salinities are read in from the hydrology file. Salt pickup or removal is read in from the demand file. The impact of the salt pickup or removal is brought into the river by the return flow of an associated diversion.

To route salt through a reservoir, complete mixing is assumed. This approach, in a simplified form, was verified by Dr. John Hendrick in his Ph.D. dissertation (1973), Colorado State University, as applicable to Lake Mead on a monthly basis. The concentration of salt in the outflow is assumed equal to a weighted

average of the beginning and ending concentrations of the salt in the reservoir.

Operational Control Data

Operational control data are input to the CRSM and include: reach identification and basin configuration; reach description data (location and identification of diversions, return flows, inflows, and reservoirs); reservoir and powerplant characteristics data; data controlling output options and various run parameters (i.e., starting and ending dates, etc.); and miscellaneous data which control the operations and conditions specific to the Colorado River Basin.

Reservoir operational characteristics data are entered in the form of polynomial equations for the following:

1. Reservoir elevation-area-capacity relationships
2. Turbine horsepower output at full gate versus head
3. Discharge versus head
4. Tailwater elevation versus flow

Polynomials for the reservoir elevation-area-capacity curves are selected to reproduce the tables used in the operations of the reservoirs.

Manufacturer's rating curves are used for the power output of the powerplants. Other reservoir operation data contained in the control file are listed below:

1. Target capacities for each month - rule curves
2. Bank storage coefficients

3. Evaporation rates for each month for all reservoirs
4. Maximum and minimum reservoir constraints
5. Maximum and minimum outlet limitations
6. Initial reservoir content and salinity

Demand Data

Varying levels of basin development may be studied by modifying the demand data base. The demand data base contains characteristics of each demand and allows for a breakdown of a demand into 10 water users. Since there may be up to 10 demands per reach, it is possible to have as many as 100 users per reach. The demand data base is not input to the model directly but is input to the SMDID (Simulation Model Demand Input Data) program. With the demand data base as input, SMDID generates the demand data for CRSM. SMDID not only generates the demand data but also produces summaries of projected depletion by water use (i.e., irrigation, M&I, power, etc.), State, and basin. These summaries provide a useful format for documenting the level of development modeled by a particular run of CRSM.

Hydrology Data

The hydrology data input to CRSM is generated by running the program MHYDRO with the hydrology data base and control data as input. The hydrology data base contains calculated natural flow and salt and natural reach gains and losses of flow and salt from 1906 to 1978; natural is defined for this purpose as historical data adjusted for human development. This adjustment is made to estimate

what the flows would be without present development on the river. The data for this data base were developed from historical stream-flow records, climatological records, cropped acreages, calculated evaporation from reservoirs, and recorded diversions and return flows. The data base has been developed for the periods 1906-1978 and will be extended periodically. The program MHYDRO not only generates the hydrology data for CRSM but also may produce tables, correlations, plots, and other reports at the option of the user. MHYDRO also performs the updating of the hydrology data base.

With most applications of the CRSS, it is important to evaluate the reaction of the system to high and low runoff periods coupled with different periods of development. This evaluation is currently performed by making several runs. With each run, the beginning year of the hydrology is shifted ahead "n" years. For example, if the model run were to be from 1981 to 2030 and "n" was set equal to 5, the first run would begin with 1981 using the 1906 hydrology, 1982 using the 1907 hydrology, etc. The second run would begin with 1981 using the 1911 hydrology and so on. Shifting the beginning year by "n" years each run and placing the earlier years to the tail end of the hydrology allows for 73 divided by n model runs to be evaluated.

Tapedit (Output Summary Program)

The TAPEDIT program was developed to save both manpower and computer resources. With TAPEDIT, the user may select certain parameters to be summarized in either tabular or

graphical form. By using TAPEDIT, many pages of output can be eliminated.

Colorado River Simulation Model Computer Resource Requirements

The CRSM is written in Fortran IV and is presently set up to run on the Bureau of Reclamation Control Data Corporation CYBER 170/730 computer at the Engineering and Research Center, Denver, Colorado. The model requires 215,000 octal 64-bit words of computer core memory storage. At present a 50-year run costs around \$20 and requires about 80 seconds of computer time.

Applications of Colorado River Simulation System

The CRSS was first applied by the Westwide study group in 1973. From 1973 to 1978, CRSS was given serious scrutiny and many changes were made to solve some of the problems and strengthen some areas of weakness that had been detected. In 1978, CRSS was applied to the WRC (Water Resource Council) Emerging Energy Technology Studies. Further improvements were made during this study period. In 1979, CRSS was used by the Office of Atmospheric Research, Bureau of Reclamation, to evaluate the potential uses and effects of weather modification or precipitation enhancement. In 1980, CRSS was used to produce data for the "Tenth Biennial Report on the Quality of the Colorado River." In 1981, CRSS was used to furnish data for WRC Emerging Energy Technology Studies in the Lower Colorado Basin. With each use of the CRSS, improvements are made. The Bureau of Reclamation

has accepted CRSS as the primary tool for simulations of the Colorado River System. Other models and methods used to indicate impacts of operational and developmental adjustments on the Colorado River are gradually being phased out. The CRSS is supported technically by a Technical Management Team, and administratively by a Steering Committee. This support draws from personnel in the Upper and Lower Colorado Regional Offices and the Engineering and Research Center.

Documentation

The complete documentation of the CRSS is contained in eight parts:

1. CRSS Executive Summary
2. Volume I Model: User's Manual
3. Volume II Model: Programmer's Manual
4. SMDID User's Manual
5. Upper Colorado River Hydrology Data Base
6. Lower Colorado River Hydrology Data Base
7. TAPEDIT User's Manual
8. MHYDRO User's Manual

For additional information regarding the CRSS please write to or call one of these offices:

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